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Assessing the impacts of the introduced channel catfish Ictalurus punctatus using the comparative functional response approach

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1 **Assessing the impacts of the introduced channel catfish *Ictalurus punctatus* using**

2 **the Comparative Functional Response approach**

3 **Abstract**

4 In the metric "Relative Impact Potential" (RIP), the functional response (FR) of a non-

5 native species can be compared to that of a native analogue and combined with the species

6 abundance to predict its environmental impact. Here, using the River Guaraguaçu (Brazil)

7 as a case study, this methodology was implemented to identify the impacts of the non-

8 native channel catfish *Ictalurus punctatus* compared to a native species *Rhamdia quelen*

9 towards small prey fish. Both species exhibited Type II FRs, however handling times

10 were lower for *I. punctatus*, resulting in a greater maximum feeding rate in this species.

11 Consequently, an RIP > 1 was found, indicating that *I. punctatus* represents a superior

12 impact to prey when compared to its native analogue. These results demonstrate that *I.*

13 *punctatus* is a potential threat to small endangered fish species. Therefore, policies to

14 avoid escapes from aquaculture should be created and the abundance of *I. punctatus*

15 controlled.

16 **Keywords**

17 alien species, aquaculture, fish, freshwater, management, Relative Impact Potential

18

1   Introduction

The introduction of non-native species to novel regions is one of the main drivers of species extinction and is considered the second major cause of global biodiversity loss after habitat destruction (Bellard, Cassey & Blackburn, 2016; Clavero & García-Berthou, 2005; Vitousek, D'Antonio, Loope & Westbrooks, 1996). Predation by non-native species can devastate native prey populations as non-native predators are often more efficient consumers of resources compared to their native counterparts (Paolucci, MacIsaac & Ricciardi, 2013; Salo, Korpimäki, Banks, Nordström & Dickman, 2007; Simberloff & Vitule, 2014). Compounding this, native prey often do not exhibit effective anti-predator behaviour due to a lack of shared evolutionary history with the new predator (Cox & Lima, 2006). These mechanisms can explain the establishment success of non-native predators and their negative impact in the recipient community (Gallardo, Clavero, Sánchez & Vilà, 2016; Latini & Petrere, 2004; Sharpe, De León, González & Torchin, 2017; Simberloff et al., 2013; Trumpickas, Mandrak & Ricciardi, 2011).

Prediction and quantification of impacts of non-native species is of great importance for conservation of biodiversity, although there is no agreed standard methodology for doing so (Kumschick et al., 2015; Parker et al., 1999; Ricciardi, Hoopes, Marchetti & Lockwood, 2013). The comparative functional response (CFR) has been proposed as an approach that "can unify invasion ecology" (Dick et al., 2017a), providing a trait-based methodology for measuring resource-use interactions of non-native species as a means of predicting their potential ecological impact. The CFR approach is based on the comparison of the functional response (FR) of non-native and trophically analogous native species, where the difference in the magnitude of the FR can predict and quantify the relative impacts of the non-native species (Dick et al., 2014).

43   A FR is defined as the relationship between consumption rate and resource

44   density (Holling, 1959b). There are three types of FR: Type I – an increasing linear

45   relationship between resource density and consumption until a threshold of satiation;

46   Type II – a decelerating rate of consumption that reaches an asymptote at higher densities;

47   and Type III – an S-shaped curve where the consumption rate first accelerates at low

48   densities and then decelerates towards satiation (Holling, 1959b). The FR type of the

49   predator can have direct effects on the stability of the prey population, for instance Type

50   II FR has destabilising effects with high consumption at low densities, whereas Type III

51   has stabilising effects with a refuge of predation at low densities (Oaten & Murdoch,

52   1975; Sinclair et al., 1998). As FRs measure the *per capita* effect of a non-native species,

53   it can be combined with the abundance of the species in the field, in a metric called the

54   Relative Impact Potential (RIP), to enhance the predictive power of this approach (Dick

55   et al., 2017b).

56   A native to North America, the channel catfish (*Ictalurus punctatus* Rafinesque,

57   1818) has been introduced worldwide for aquaculture and sport fishing purposes (CABI,

58   2019). The species was first introduced in Brazil in 1971 and, having potentially escaped

59   accidentally from aquaculture cages (Orsi & Agostinho, 1999; Welcomme, 1988), it is

60   now widely found in Brazilian water bodies (Cruz-Spindler et al., 2012; Ota, Message,

61   Graça & Pavanelli, 2015; Zanatta et al., 2010). As a non-native species, *I. punctatus* is a

62   potential threat to local fish assemblages through competition and predation of native

63   species (e.g. Matsuzaki et al., 2011; Townsend & Winterbourn, 1992; Troca & Vieira,

64   2012). For example, the decline and extinction of species, such as the razorback sucker

65   *Xyrauchen texanus,* in communities invaded by *I. punctatus* has been reported (CABI,

66   2019). Additionally, *I. punctatus* demonstrates high rates of dispersal, which is aided by

67   its ability to adapt to a wide range of habitats (Olden & Poff, 2005).

68   The aim of the present study was to apply the CFR approach and the RIP metric

69   to assess the potential impacts of the invasive *I. punctatus* in a highly-diverse river in

70   Brazil, the River Guaraguaçu. The abundance of the species is not constantly monitored,

71   but there are reports about the establishment of this species in the river basin, as well as,

72   in other basins of the Paraná State (Vitule, Umbria & Aranha, 2005; Vitule, 2008). Based

73   on the species traits and invasion history of *I. punctatus* (Gutierre, Vitule, Freire &

74   Prodocimo, 2014; Tatarenkov, Barreto, Winkelman & Avise, 2006; Townsend &

75   Winterbourn, 1992; Wellborn, 1988), and considering its taxonomic distinctiveness

76   within the recipient community (Ricciardi & Atkinson, 2004), the likely impact of *I.*

77   *punctatus* on native species and ecosystems is through an elevated consumption of small

78   stream fishes.

79   To address the paucity of research on non-native species impacts in South

80   American countries (Bellard & Jeschke, 2016; Speziale, Lambertucci, Carrete & Tella,

81   2012; Vitule, Freire, Vazquez, Nuñez & Simberloff, 2012), the present study aims to

82   enhance the understanding of the impacts of introduced predators in the Neotropical

83   region, where biodiversity is both rich and threatened (Lowry et al., 2013; Myers,

84   Mittermeier, Mittermeier, da Fonseca & Kent, 2000).

85   **2   Methods**

86   *2.1   Species used*

87   *Ictalurus punctatus* is a nocturnal forager that uses a variety of habitats with preference

88   for shallow warm waters (Bayley & Harrison, 1948; Braun & Phelps, 2016; Jordan,

89   Neumann & Schultz, 2004), detecting food using olfactory and visual cues (Becker,

90   1983). Young *I. punctatus* feed mainly on insects, but adults are usually omnivorous and

91   prey also on fish (Bailey & Harrison, 1948; Braun & Phelps, 2016; Hill, Duffy &

92   Thompson, 1995; Tyus & Nikirk, 1990). The species has opportunistic behaviour and is

93   generalist, preying on a wide range of available resources in non-native regions (Endo et

94   al., 2015; Haubrock et al., 2018).

95   The FRs of the non-native channel catfish *I. punctatus* were compared to a native

96   consumer, the South American silver catfish *Rhamdia quelen* (Quoy & Gaimard, 1824),

97   which is a benthic species widely distributed in lakes, reservoirs and rivers of Central and

98   South America (Gomes, Golombieski, Gomes & Baldisserotto, 2000; Silfvergrip, 1996).

99   There are few studies on the biology of *R. quelen*, which like *I. punctatus* is representative

100 of the Siluriformes and is generally described as nocturnal and omnivorous when mature

101 (Bailey & Harrisson, 1948; Gomes et al., 2000; Goudie, Davis & Simco, 1983). Adults

102 of *R. quelen* are considered generalists, feeding on fish, crustaceans, insects, vegetation

103 and organic detritus (Guedes, 1980; Meurer & Zaniboni Filho, 1997). *Ictalurus punctatus*

104 and *R. quelen* have many similarities in their anatomic digestive systems and diet

105 (Piedras, Pouey & Moraes, 2006) which make *R. quelen* an appropriate resident

106 comparator for *I. punctatus* in the FR experiments described here.

107   Both species also spawn in the spring, with temperature an important factor in

108 reproduction (Becker, 1983; Gomes et al., 2000). *Rhamdia quelen* has low fecundity rates

109 and do not present parental care (Gomes et al., 2000). Females of *I. punctatus* have around

110 8,000 eggs per kg body weight and males guard the eggs during a period of incubation of

111 5 to 10 days (Becker, 1983). *Ictalurus punctatus* reaches sexual maturity at 300–375 mm

112 in total length (TL), whereas *R. quelen* generally matures at 134–175 mm TL (Gomes et

113 al., 2000; Jackson, 2004; Shephard & Jackson, 2005).

114   Blue tetra *Mimagoniates microlepis* (Steindachner, 1877)*, a congeneric of the

115 locally and nationally threatened *M. lateralis* (Abilhoa & Duboc, 2004; Rosa & Lima,

116 2008; MMA, 2014), is abundant in natural water bodies and was used as prey in

117   experimental trials. Both *Mimagoniates* species are sympatric and are representatives of

118   Glandulocaudinae, which is characterised by small stream fishes (Braga, Braga, & Vitule,

119   2013; Menezes & Weitzman, 2009). *Mimagoniates lateralis* is the smallest species of the

120   genus, reaching maximum 40 mm standard length (Menezes & Weitzman, 2009; Rosa &

121   Lima, 2008).

122   *2.2   Experimental design*

123   For the experimental protocol (Figure S1), which was approved by the Ethics

124   Commission on the Use of Animals of the Biological Sciences Department of the Federal

125   University of Paraná (CEUA/BIO UFPR – Certificate nº1027), juveniles of predator fish

126   species (*I. punctatus* and *R. quelen*) were obtained in local aquaculture farms and stored

127   in tanks of 300 L in the lab. Each species was kept in a different tank with constant

128   aeration and filtration for acclimation during 30 days. Prey fish were collected in the field

129   using fishing nets and kept in an 80 L aquarium, with constant aeration and filtration, and

130   were also acclimated for 30 days. The temperature in the lab was kept at 22–26°C under

131   a natural light regime. During the acclimation period predators were fed every 48 h with

132   sausage to standardise prior experience.

133   Experiments were performed in 10 L opaque plastic boxes (35 × 20 × 25 cm)

134   with constant aeration. Individuals of predator species were randomly selected one day

135   prior to use and placed in the experimental aquariums for 24 h acclimation. Predators (n

136   = 9 per species) were size-matched with respect to total length (*R. quelen*: 16.39 cm ±

137   1.15 and *I. punctatus*: 16.83 cm ± 2.14; Students' *t*-test, $t = –0.55$, df = 16, $p = 0.59$). Each

138   predator specimen was reused in two more trials with different initial densities. After the

139   acclimation period, they were held without food for 72 h to standardise hunger levels.

140   Predators were then presented with the prey at five initial densities (2, 5, 10, 20, and 30

141   individuals), with five replicates per density. Prey were also size matched with respect to

142 total length by visual selection ($\approx$ 3 cm). Experiments were initiated at 14:00 and prey

143 consumption was recorded after 24 h. Controls were three replicates of each initial density

144 of prey in the absence of predators.

145 *2.3   Data analysis*

146 The FR type was determined from a logistic regression of prey density by the proportion

147 of consumed prey, as proposed by Juliano (2001). A negative first order term indicates a

148 Type II FR, whereas a positive first order term followed by a negative second order term

149 indicates a Type III FR (Pritchard, Paterson, Bovy & Barrios-O'Neill, 2017). The FR

150 curves and the parameters attack rate (*a*) and handling time (*h*) were modelled using

151 Maximum Likelihood Estimation (Bolker, 2008) with the Rogers' (1972) random

152 predator equation that considers the depletion of prey without replacement along the

153 experimental period:

154 $$N_e = N_0 \{1 - \exp[a(N_e h - T)]\} \tag{1}$$

155 where N_e is the number of prey consumed, N_0 is the initial density of prey, *a* is the attack

156 rate, *h* is the handling time and T is the experimental period, given in days. The attack

157 rate (*a*) is the instantaneous capture rate, *i.e.* the rate at which the consumer encounters

158 resource items per unit of resource density; and the handling time (*h*) is the time spent

159 capturing and consuming the prey item (Brose, 2010; Holling, 1959a; Jeschke, Kopp &

160 Tollrian, 2002). The *h* was used to estimate the maximum feeding rate (1/*h*T), which

161 represents the FR curve asymptote. To compare the FR of each species, the parameters *a*

162 and *h* were compared between predators using the indicator variables method, as the

163 following equation:

164 $$0 = N_0 - N_0 \exp\{[a + Da(j)]\{h + Dh(j)](N_e) - T\}\} - N_e \tag{2}$$

165   where j is an indicator variable that takes value 0 for *R. quelen* and 1 for *I. punctatus*. The

166   parameters Da and Dh estimate the differences between the predators in the value of the

167   parameters a and h, respectively. If these parameters are significantly different from zero,

168   then the two species differ significantly in the corresponding parameters (Juliano, 2001).

169   To visualise the uncertainty around the fitted functional responses, 95% confidence

170   intervals were constructed by bootstrapping (n = 2000) data around FR curves. If

171   confidence intervals do not overlap, then it can be stated that species FRs differ (Paterson

172   et al., 2015). Analyses were carried in R v. 3.4.1 (R Core Team, 2015) using the 'frair'

173   package (Pritchard et al., 2017) at 0.05 significance.

174   The Relative Impact Potential (RIP) metric was calculated using the following

175   equation, according to proposed by Dick et al., 2017b:

176
$$\text{RIP} = \frac{\text{FR non-native}}{\text{FR native}} \text{ X } \frac{\text{AB non-native}}{\text{AB native}} \tag{3}$$

177   where FR is the estimated maximum feeding rate ($1/h$T) and AB is the field

178   abundance/biomass of the species. When RIP < 1, the non-native species is predicted to

179   have less impact than the native equivalent; when RIP = 1, there is no impact above that

180   driven by native equivalents; whereas RIP > 1 indicates a likely non-native ecological

181   impact (Dick et al., 2017b). Data of total abundance and biomass were taken from

182   literature, from samples collected in River Guaraguaçu using a variety of fishing gears

183   (Vitule, 2008) (Table S1). As data from different methods of capture and of different

184   fishing efforts were compiled (Table S1), the capture per unit effort (CPUE) was

185   calculated to standardise these differences. This was the number of fishes captured

186   divided by the number of fish hooks or area of gill nets, multiplied by fishing effort in

187   hours.

188 **3   Results**

189 None of the prey fish died in any of the control replicates, therefor prey mortality in the

190 experimental trials was attributed to predation. Both species obtained a negative first-

191 order term from logistic regressions, indicating a Type II FR (Table 1, Figure 1).

192 Parameter estimates of the FR model were all statistically significant (Table 1). The attack

193 rate did not differ between species ($Da = -0.646$, $z = -0.447$, $p = 0.655$), but the handling

194 time was significantly lower for *I. punctatus* ($Dh = 0.053$, $z = 2.209$, $p < 0.05$), and thus

195 a higher maximum feeding rate was obtained (Table 1).

196   The RIP calculated using field data on total abundance did not demonstrate a

197 greater impact of the non-native species (RIP $<$ 1, Table 2). Considering biomass, the

198 impact of *I. punctatus* was found to be similar to the native species *R. quelen* (RIP $\approx$ 1,

199 Table 2). However, using CPUE data, *I. punctatus* was found to have a greater impact

200 (RIP $>$ 1, Table 2).

201 **4   Discussion**

202 Both predator species in the present study demonstrated a Type II FR when exposed to

203 *M. microlepis*. Most, if not all, of the prey were consumed at low densities, which

204 suggests that in open waters this could lead to destabilising effects on the local population

205 (Holling, 1959a; Murdoch & Oaten, 1975; Sinclair et al., 1998). A Type II FR may

206 therefore pose a greater concern in open waters, where endangered, such as *M. lateralis*,

207 are often found to exist in small populations (IUCN, 2012; Sinclair et al., 1998).

208   The CFR approach provided evidence that *I. punctatus* is likely to exert an

209 ecological impact to native small fish prey, and it is possible that other small-bodied

210 endangered fish species suffer predation pressure from *I. punctatus* in a similar manner

211 as *M. microlepis*. Despite the overlap of FR curves of *I. punctatus* and its native

212 comparator *R. quelen* (Figure 1), the results of the present study suggest that *I. punctatus*

213 exerts a greater predation pressure on *M. microlepis*, with a significant lower handling

214 time, and therefore a higher maximum feeding rate. Lower h and consequently higher

215 $1/h$T, due to faster rates in processing prey, can explain the superior impact of invaders

216 (Alexander, Dick, Weyl, Robinson & Richardson, 2014). The lower handling time of *I.*

217 *punctatus* (Table 1) may be due to differences in the resource acquisition ability of the

218 species (Alexander et al., 2014). *Ictalurus punctatus* has taste buds across its body and

219 within its barbels, which aid in perception of food and trigger feeding behaviour (Caprio

220 et al., 1993; Valentincic & Caprio, 1994). *Ictalurus punctatus* also has relatively larger

221 eyes than other siluriform catfishes, which may facilitate visual predation in clean waters,

222 such as of the experimental conditions (Davis, 1959). The similar FRs of *I. punctatus* and

223 *R. quelen* towards the prey (Figure 1) also suggest that these species may have niche

224 overlap, resulting in either resource competition or repartition in open waters. Both

225 species seems to use the same strategy to find resources, as their barbels are sensitive to

226 amino acids or hydrolysed proteins, which triggers feeding behaviour (Caprio, 1975;

227 Broggi, 2014).

228   *Ictalurus punctatus* are less abundant than native *R. quelen* in the River

229 Guaraguaçu, which suggests a lower relative predation impact than the native species.

230 However, using standardised CPUE data, a different result emerged, with *I. punctatus*

231 presenting a higher abundance (Table 2), and therefore a potentially greater impact than

232 *R. quelen*. Using only the FR provides a modestly-powered predictor of non-native

233 species impacts, because a low FR can be compensated by high abundance in the field

234 (Laverty et al., 2017). The results obtained here, of a greater RIP using CPUE field data

235 (Table 2), are sufficient to justify the need of management and control of *I. punctatus*

236 population. Early interventions may be successful in avoiding non-native species impacts

237   (Simberloff, 2003), and in the present case, the results provide evidence to motivate the

238   immediate action to manage *I. punctatus* at low population levels.

239   Propagule pressure is widely believed to play a fundamental role on the

240   successful establishment and permanency of non-native species, contributing to its

241   continuous impact (Copp, Templeton & Gozlan, 2007; Kolar & Lodge, 2001; Ruesink,

242   2005). The juvenile *I. punctatus* used in these experiments were obtained from local

243   aquaculture, which is recognised as the major pathway of introduction of *I. punctatus* and

244   other freshwater invasive species (CABI, 2019; Casal, 2006; Gozlan, 2008; Naylor,

245   Williams & Strong, 2001). *Ictalurus punctatus* is among the most cultured freshwater

246   fishes globally, and its global total production in 2016 reached 432,932 tons (FAO, 2018).

247   There are many fish-farms in Paraná State that cultivate and sell young-of-the-year *I.*

248   *punctatus* despite a legislation that classifies this species as Category I, which has its

249   "*transportation, breeding, release or translocation, cultivation, propagation,*

250   *commercialization, donation or intentional acquisition prohibited by any means*"

251   (Environmental Institute of Paraná, 2015). Despite this, the production of *I. punctatus*

252   continues to increase, and the risk of escapes from aquaculture ponds is a constant threat

253   in Neotropical streams, contributing to a high propagule pressure (Forneck, Dutra,

254   Zacarkim & Cunico, 2016; Lima Junior, Pelicice, Vitule & Agostinho, 2012; Vitule,

255   Freire & Simberloff, 2009). This failed attempt to ban the introduction of *I. punctatus* in

256   Paraná could be responsible for the declines in status of many endemic fishes (Lima

257   Junior et al., 2018; Pelicice et al., 2017; Vitule et al., 2009). Therefore, the cultivation of

258   the *I. punctatus* should be avoided in Paraná in order to reduce its spreading into natural

259   water bodies.

260   Besides constant introductions of *I. punctatus*, the species' reproductive

261   behaviour (guarders, nest spawners) is more specialised than that of *R. quelen*

262   (nonguarders, open substratum spawners) (see Balon, 1975). The male *I. punctatus*

263   guards the eggs until they hatch, a feature that may favour the establishment of the non-

264   native species in the field (Marchetti, Moyle & Levine, 2004; Tatarenkov et al., 2006).

265   Also, predation of *I. punctatus* by native fishes in the study region is unlikely due to the

266   dorsal and pectoral spines of *I. punctatus* (Bosher, Newton & Fine, 2006).

267   In the present study, juveniles of similar body size were used, which contrasts

268   natural populations. Predator body-size influences most aspects of feeding behaviour and

269   there are allometric relationships between body size and the FR parameters, with

270   increases in *a* and decreases in *h* as predator size increases (Brose, 2010; González-Suárez

271   et al., 2011; Miller, Crowder, Rice & Binkowski, 1992; Vucic-Pestic, Rall, Kalinkat &

272   Brose, 2010). In the case of the two study species, *I. punctatus* can reach larger adult sizes

273   than *R. quelen,* as the first can be mature at size 300 mm TL and *R. quelen* is already

274   mature at 175 mm TL (Gomes et al., 2000; Jackson, 2004; Shephard & Jackson, 2005),

275   which may lead to an increased *per capita* effect of the non-native species that could

276   influence the FR results.

277   As with many fishes, the degree of piscivory tends to increase in *I. punctatus*

278   with increasing body length (Starostka & Nelson, 1964). As juveniles were used here, it

279   can be expected a greater *per capita* effect of adults of in the field. Furthermore,

280   omnivores like *I. punctatus* tend to present a Type II FR when exposed to a single type

281   of prey, and the presence of an alternative food source may therefore affect our results

282   (Médoc, Thuillier & Spataro, 2017; Murdoch & Oaten, 1975). Indeed, alternative food

283   availability has been shown to change FRs of amphipods, killer shrimp *Dikerogammarus*

284   *villosus* and the freshwater shrimp *Gammarus pulex*, with the superior consumption of

285   the invasive *D. villosus* disappearing when it was presented with an alternative non-

286   animal food (Médoc, Thuillier & Spataro, 2017).

287   Differences in predator biomass also likely strengthen the impact of *I. punctatus*.

288   The mean biomass of *I. punctatus* specimens captured in the River Guaraguaçu was more

289   than twice of the native species and the RIP using biomass was ≈ 1 (Table 2), which

290   suggests that the impact of *I. punctatus* in the wild is greater than the native predator

291   despite its lower abundance. Neither predator species nor size alone can predict

292   consistently the FR type and its associated parameters, so both predator identity and size

293   should be considered to assess fully the potential ecological impacts of a non-native

294   species on invaded communities (Anderson, Linares, Dodson & Semlitsch, 2016; Guo,

295   Sheath, Amat Trigo & Britton, 2016).

296   It is important to consider other factors that may alter FR results, such as habitat

297   complexity (Alexander, Dick, O'Connor, Haddaway & Farnsworth, 2012; Barrios-

298   O'Neill, Dick, Emmerson, Ricciardi & Macisaac, 2015), which in some cases can change

299   the FR type and parameters. This can occur if habitat complexity acts as a refuge for prey

300   in low density (Alexander, Kaiser, Weyl & Dick, 2015) or contributes to predation of

301   ambush predators, resulting in a higher consumption rate (Santos, García-Berthou,

302   Hayashi & Santos, 2013). This context-dependency factor may also be an important

303   feature to be tested in the FR of *I. punctatus*, as the River Guaraguaçu has been invaded

304   by the African signalgrass *Urochloa arrecta*, a macrophyte that increases habitat

305   complexity (Michelan, Thomaz, Mormul & Carvalho, 2010; Thomaz & Cunha, 2010;

306   Vitule, Umbria & Aranha, 2006).

307   To quantify and predict the impacts of non-native species is of fundamental

308   importance to conservation efforts, because such data are needed in order to create plans

309   for management and control of damaging species. The CFR approach and the RIP metric

310   have been shown as an effective tool for predicting the impact of existing and emerging

311   high impact non-native species and can be performed elsewhere in a very simple fashion

312 (Alexander et al., 2014; Dick et al., 2017a, 2017b; Laverty et al., 2017). Therefore, the

313 CFR approach is of particular usefulness in both developing and developed countries

314 because data on non-native fish impacts are lacking for most species. Whereas, data on

315 non-native species impacts are even more scarce in less developed regions, where the

316 number of potentially threatened endemic species is often high (Frehse, Braga, Nocera &

317 Vitule, 2016; Lövei, Lewinsohn & Network, 2012; Nuñez & Pauchard, 2010; Vitule et

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625   **Figure legend**

626   **Figure 1.** Type II Functional Response curves for channel catfish *Ictalurus punctatus* (dashed line) and

627   South American silver catfish *Rhamdia quelen* (solid line) preying on blue tetra *Mimagoniates*

628   *microlepis*. Points indicate mean consumption per density. Shading represents bootstrapped ($n = 2000$)

629   95% confidence intervals for each species.

630

631

632   **Assessing the impacts of the channel catfish *Ictalurus punctatus* using the**

633   **Comparative Functional Response approach**

634   **Table S1**. Field data on total abundance (*n*), capture per unit effort

635   (CPUE) and total biomass (in grams) of channel catfish *Ictalurus*

636   *punctatus* and South American silver catfish *Rhamdia quelen*

637   captured in 17 standardised samples, between 2005 and 2007, using

638   different fishing gears. Data from Vitule (2008). Long lines were of

639   10 m length, and gill nets were of 30×1.70 m, with exposure times

640   in all cases being 1500 hours.

Fishing gear (and mesh size)	Effort	*n*	CPUE	Biomass (g)

Ictalurus punctatus					
	Longline	3 longlines with 10 fish hooks	8	0.000178	9312
	Gill net (20 mm)	Gill net	5	6.54E-05	1069
	Gill net (40 mm)	Gill net	4	5.23E-05	2075
	Gill net (60 mm)	Gill net	1	1.31E-05	740
	Fishing rod	4 anglers, ≈ 60 h	12	0.05	14496
Rhamdia quelen					
	Longline	3 longlines with 10 fish hooks	40	0.000889	14106
	Gill net (20 m)	Gill net	31	0.000405	8133
	Gill net (40 mm)	Gill net	33	0.000431	14768
	Fishing rod	4 anglers, ≈ 60 h	8	0.033333	1978

641

642